Fuel Cell Vehicle Systems Analysis

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Outline

- Objectives
- Approach
- Timeline of Highlights
- Accomplishments
- Addressing Reviewer Comments
- Industry Interactions
- Future Plans
- Summary

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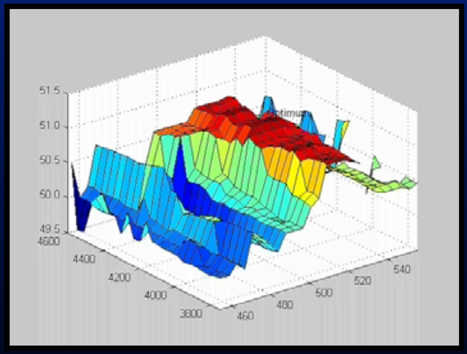
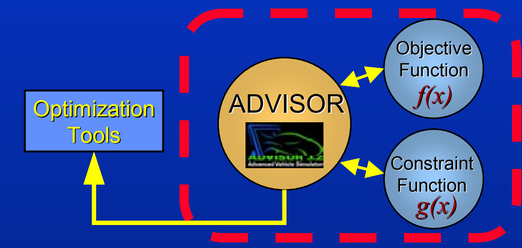


Objectives

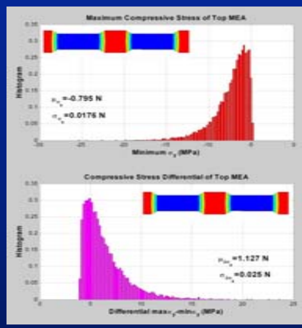
- Provide DOE and industry with technical solutions and modeling tools that accelerate the introduction of robust fuel cell technologies
- Quantify benefits and impacts of HFC&IT development efforts at the vehicle level (current status evaluation)
- Understand sensitivity of fuel cell technical target values and provide recommendations to DOE program managers (future goal evaluation)

Approach

- Develop and link to existing component and vehicle models to enhance systems analysis capabilities



- Work with industry to apply robust design techniques, optimization tools, and CAE tools to overcome technical barriers



- Study benefits of fuel cell system and vehicle design scenarios and transfer to industry

- Assess impact of various technical team targets at component level

Highlights and Milestones

Planned
Completed
* = milestone

6/02	Presented FC response time study results at FutureCar Congress
10/02	Presented fuel cell system model evaluation study at 202nd Electrochemical Society Meeting
10/02	Incorporated two detailed fuel cell system models into ADVISOR vehicle simulation program
11/02	Presented the Technical Targets Tool to DOE
3/03	Developed FEA models of fuel cell components and successfully demonstrated the application of robust design techniques
4/03	Presented results of 4 fuel cell system studies at ASME/RIT Fuel Cell Technology Conference
6/03	Results of gasoline reformer warm-up fuel economy impacts study to be presented at 2003 Future Transportation Technology Conference
7/03*	Expand database of fuel cell components
9/03*	Summarize the influence of key fuel cell program technical targets on fuel consumption reduction
9/03	Complete initial applications on reformer, end-plate design, stack pressure profile and high-temperature stack design
9/03*	Publish technical report on methodology for applying robust design techniques to fuel cell components

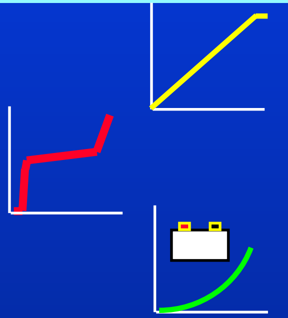
Accomplishments

Analyzed Fuel Economy Impacts of Gasoline Reformer Warm-up

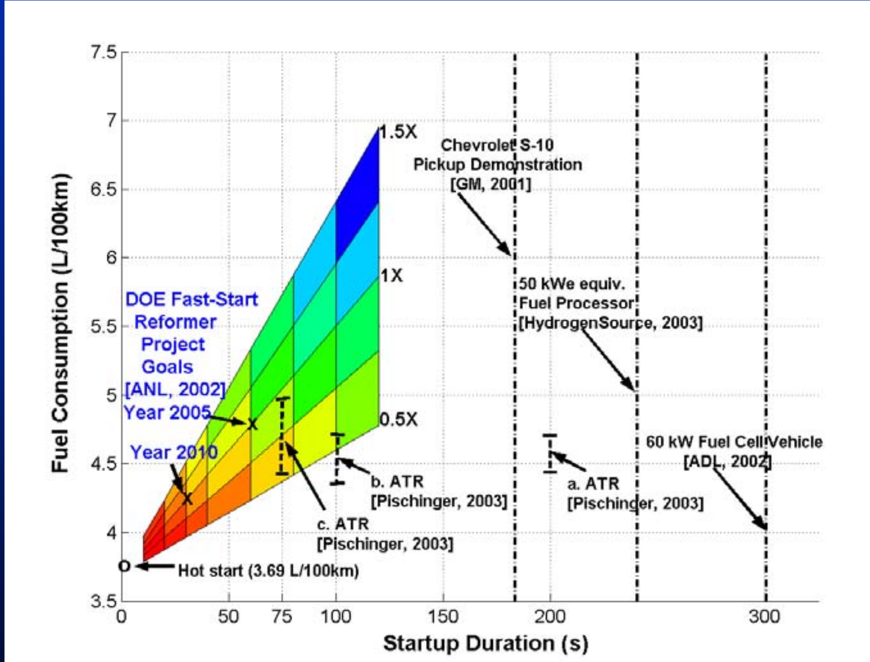
A. Allow warm-up period before FTP starts

B. Design reformer and fuel cell system to provide minimum power requirements for FTP cycle with no energy storage

C. Hybridize to balance out drive cycle requirements with achieving reasonable/efficient reformer startup time



Reformer Warmup Time (s)	Power (kW)	Cum. Raw Energy [Usable] (Wh)	SOC Window (%)	Nom. Battery Pack Total Energy (Wh)
30 s	13.5	15	20	75
60 s	13.5	45	20	225
195 s	25.7	158	20	790
10 min	25.7	658	20	3290
Toyota Prius	25	--	~5	1781
Honda Insight	6	--	~10	936
Honda Civic	n/a	--	n/a	864



- Drive cycle traction power and energy demands satisfied with relatively small battery

- Fuel economy penalty significant if duration is long or fuel rate is high

Accomplishments
Two Detailed Fuel Cell System Models in ADVISOR

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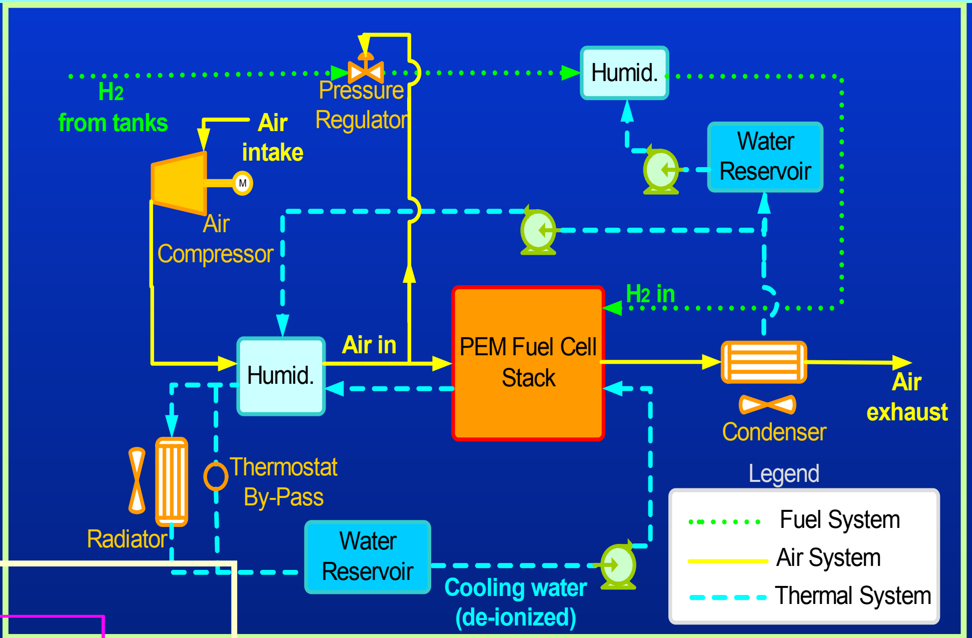
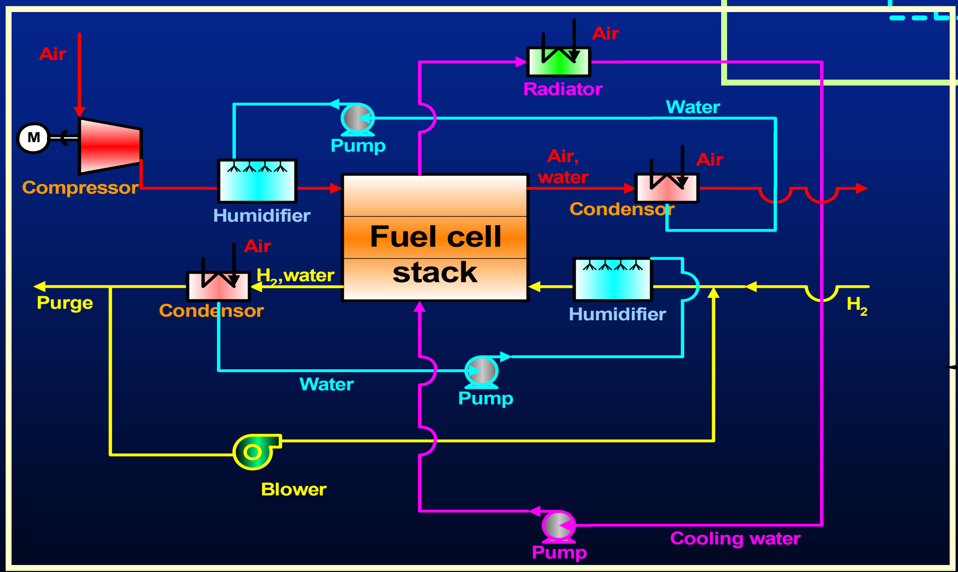


the Virginia Tech Model



the KTH Model

Accomplishments
Range of Model Complexity in ADVISOR

More Detail

KTH Model
- Springer et. al. fuel cell model
- thermodynamic library
- balance of plant components
- water transport in MEA

*** User-defined model ***
- configurable subsystem structure
- ability to link to fuel cell models in other tools (e.g. Saber, Simplorer,…)

VT Model
- parametric polarization curve
- system thermal model
- balance of plant components
- variable operating pressure

Less Detail

Simple Polarization Curve
- defined current and voltage
- simplified balance of plant

Net Power vs. Efficiency
- single curve
- scalability

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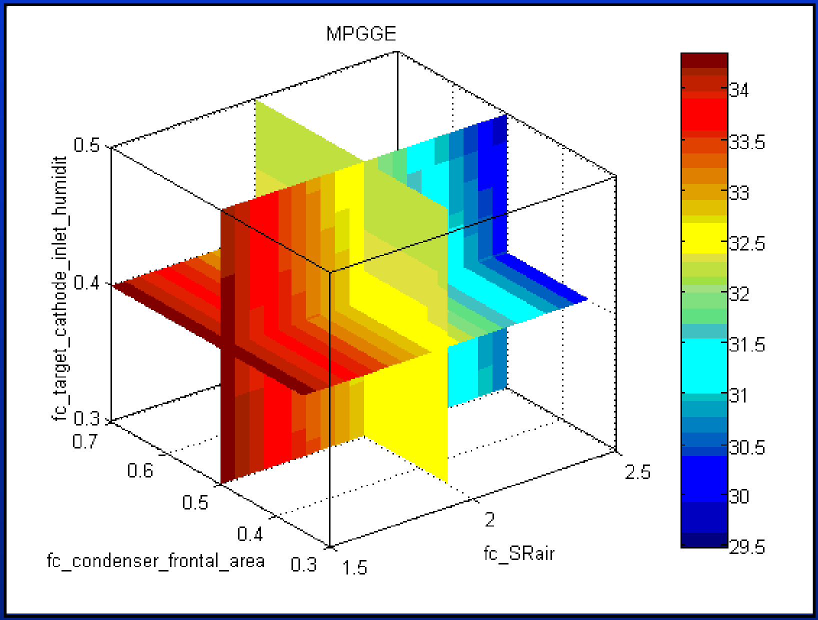
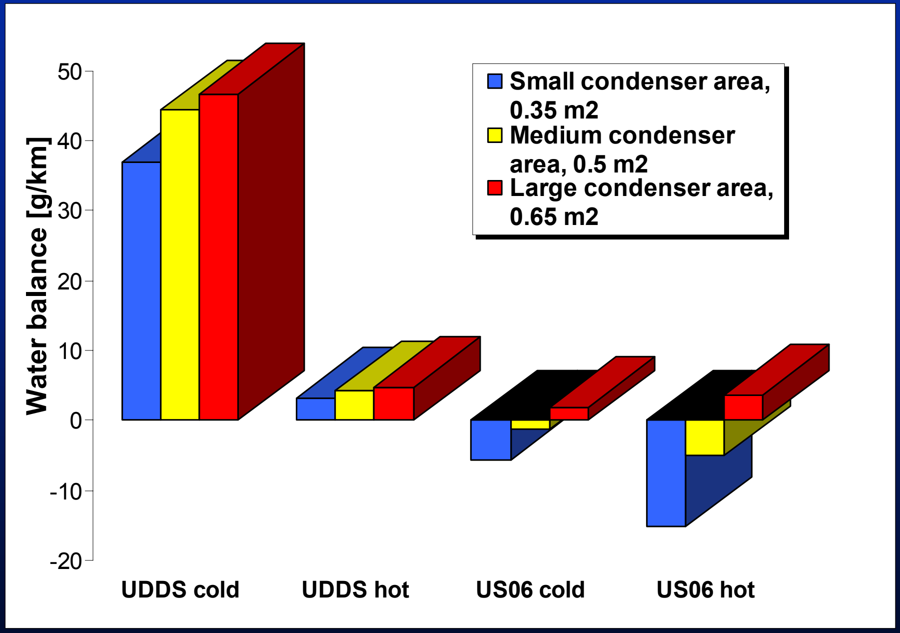
Accomplishments
Water Balance Sensitivities Assessed



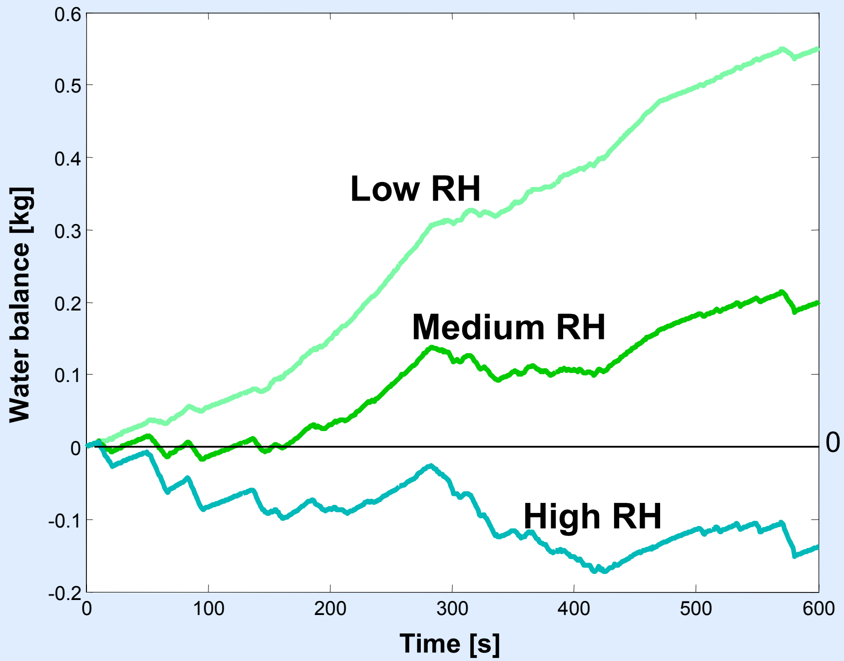
- Assessed water balance sensitivity in vehicle environment (drive cycles)
- Impact of condenser size and startup conditions quantified

UDDS:
sensitive to cold/hot start

US06:
sensitive to condenser size



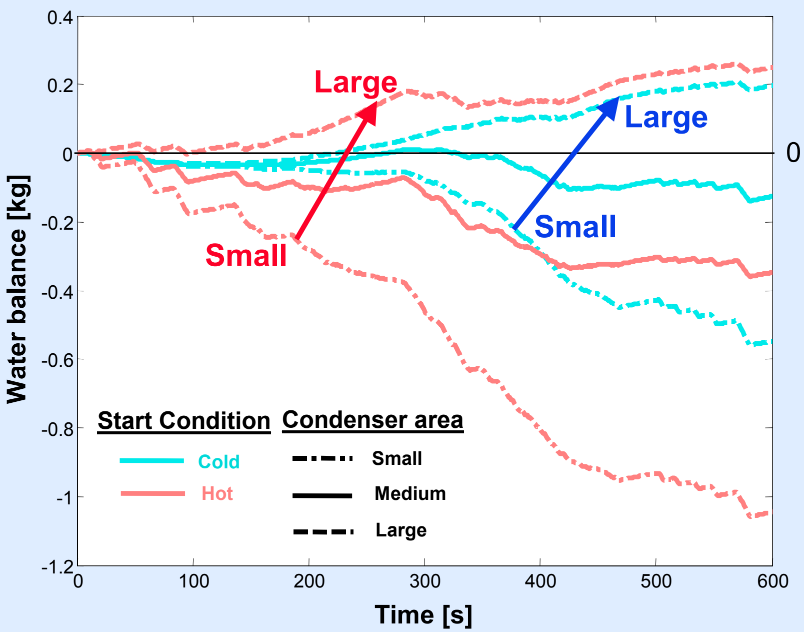
Accomplishments
Water Balance Variability on the US06 Drive Cycle



Positive WB at low relative humidity requirements

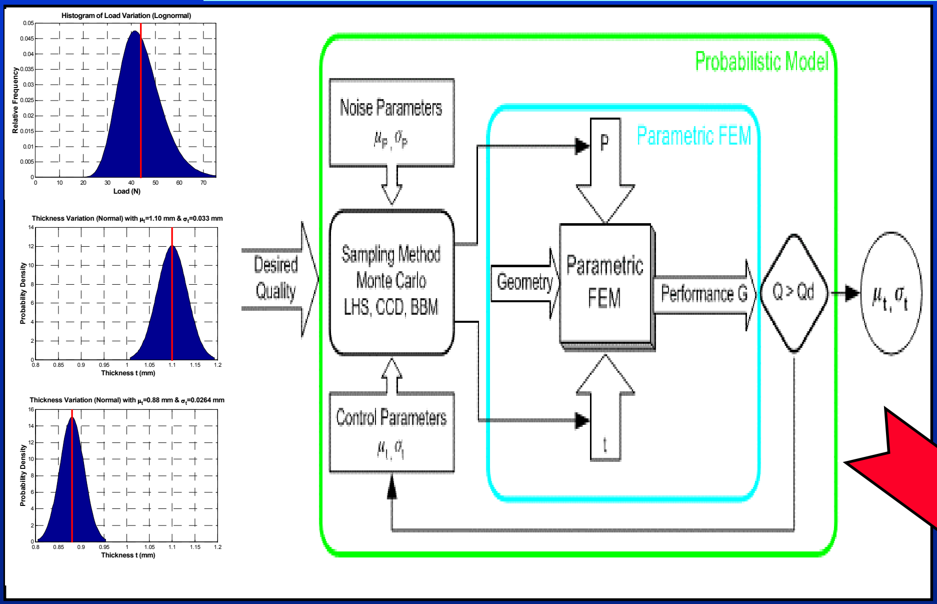
Cathode Rel. Humidity Requirements

Condenser Area



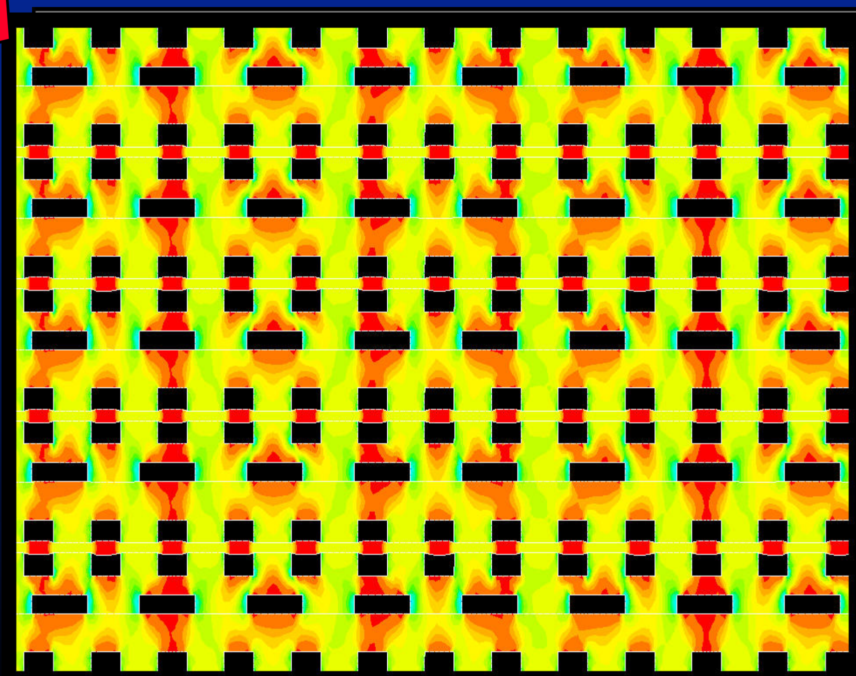
Better WB at low temperature operation

Accomplishments
Robust Designs of Fuel Cell Components



Collaborative effort with industry to apply robust design techniques to fuel cell components:

- Parametric FEA modeling
- Probabilistic design and optimization techniques integrated with FEA
- Topology optimization for reduced mass and improved pressure profiles

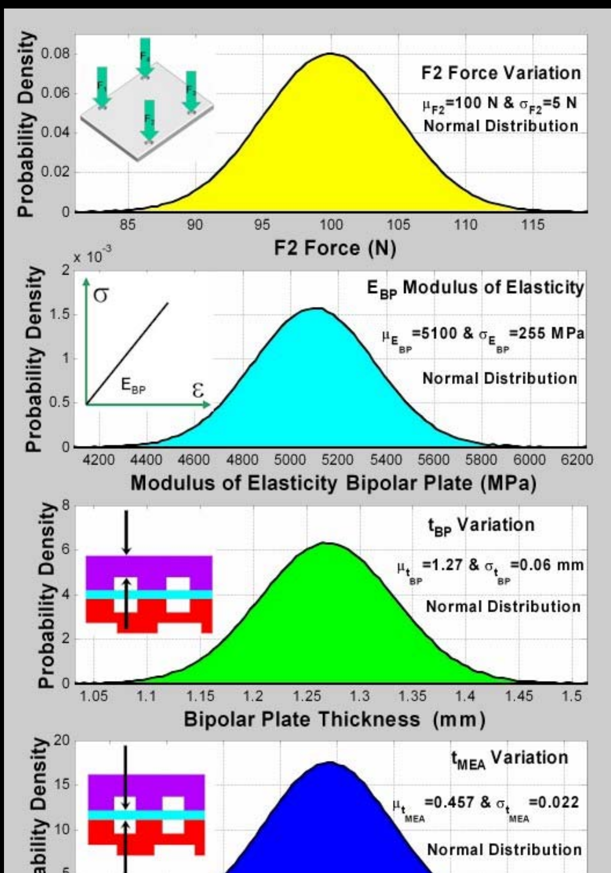


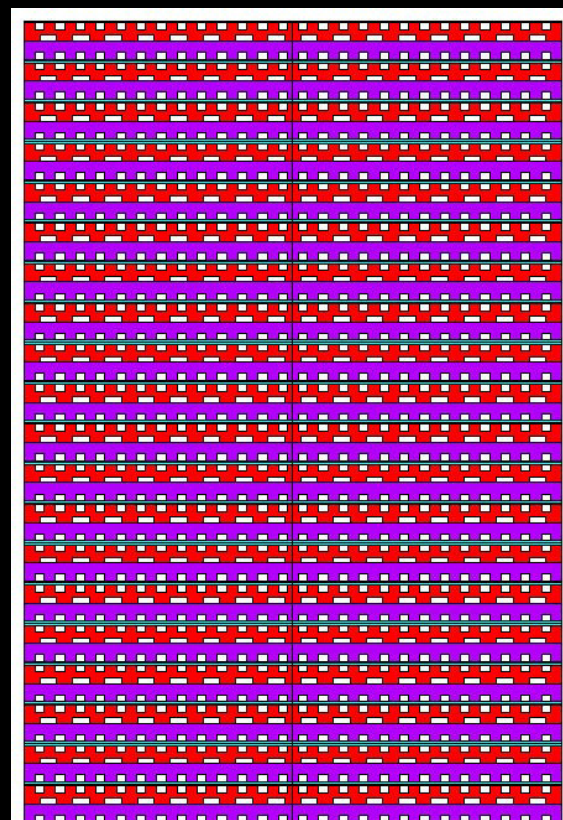
Solutions to real-world technical issues:

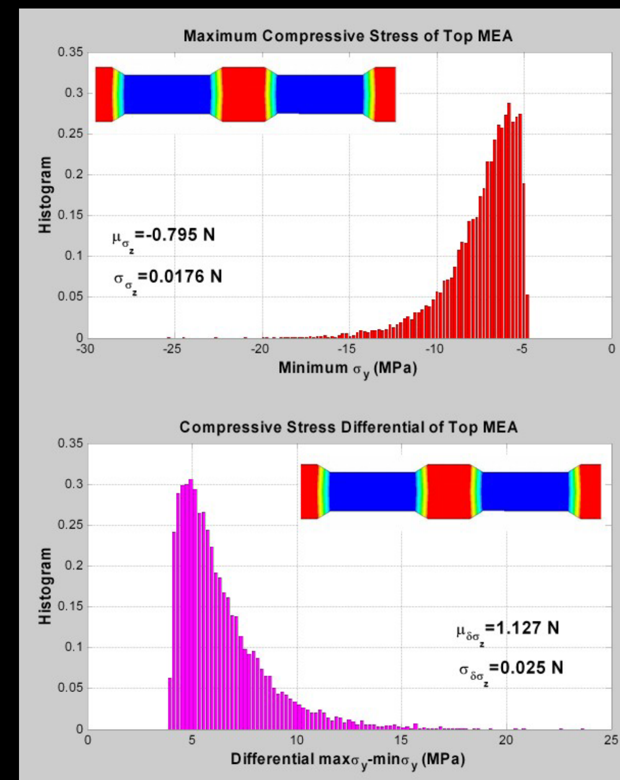
- improved thermal mechanical fatigue of ATR
- analyzed thermal efficiency of ATR
- improved pressure distribution within stack
- quantified sensitivity of design factors to non-uniform MEA pressure distribution

Accomplishments
Robust Designs of Fuel Cell Components

Statistical Distribution of Material and Manufacturing Variations → **Parametric FEA Model of Fuel Cell Stack** → **Statistical Distribution of Output Performance Measures**

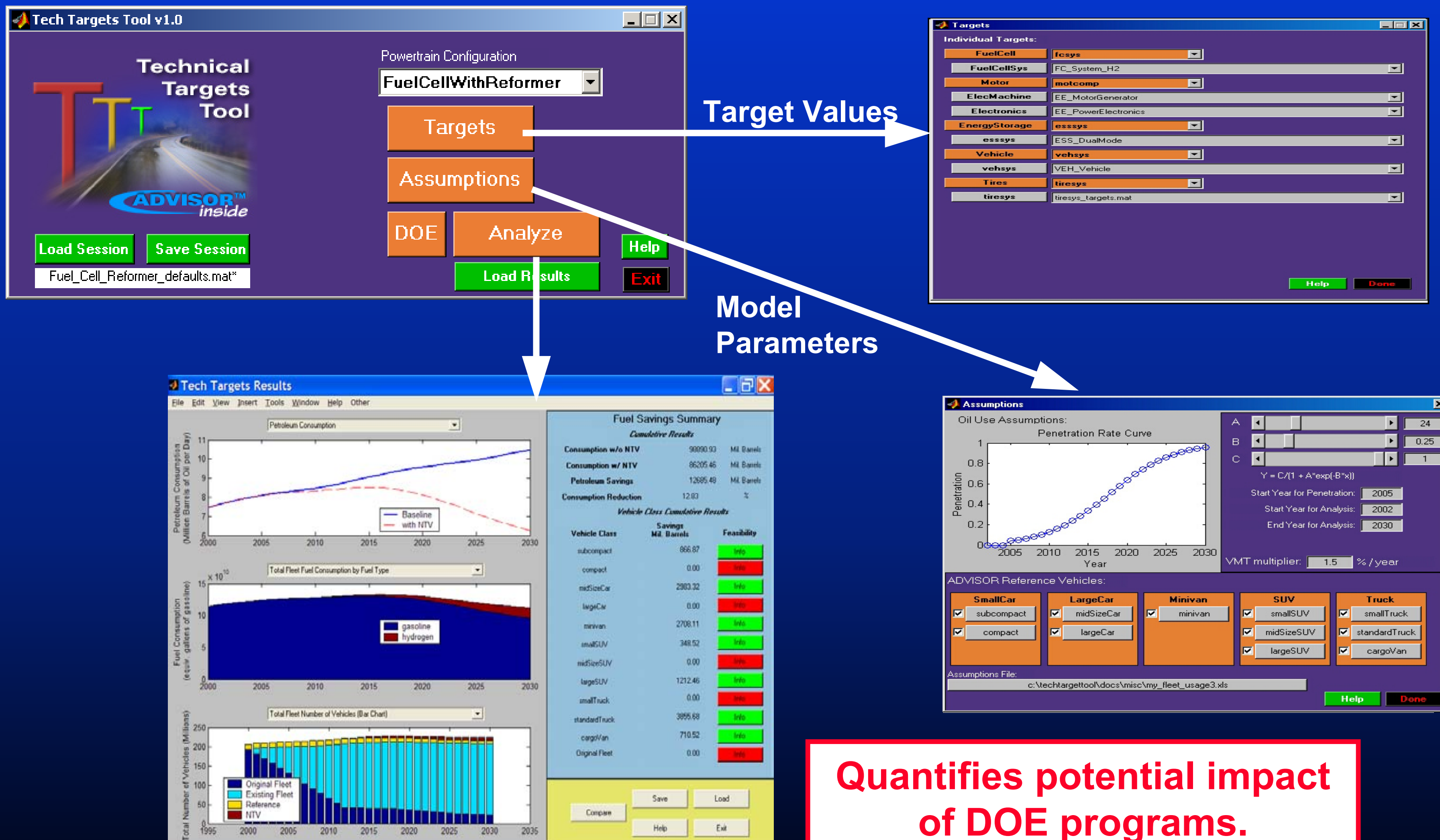






Published methodology for assessing the "Effect of Material and Manufacturing Variations on MEA pressure Distribution" ***(co-authored with Plug Power)***

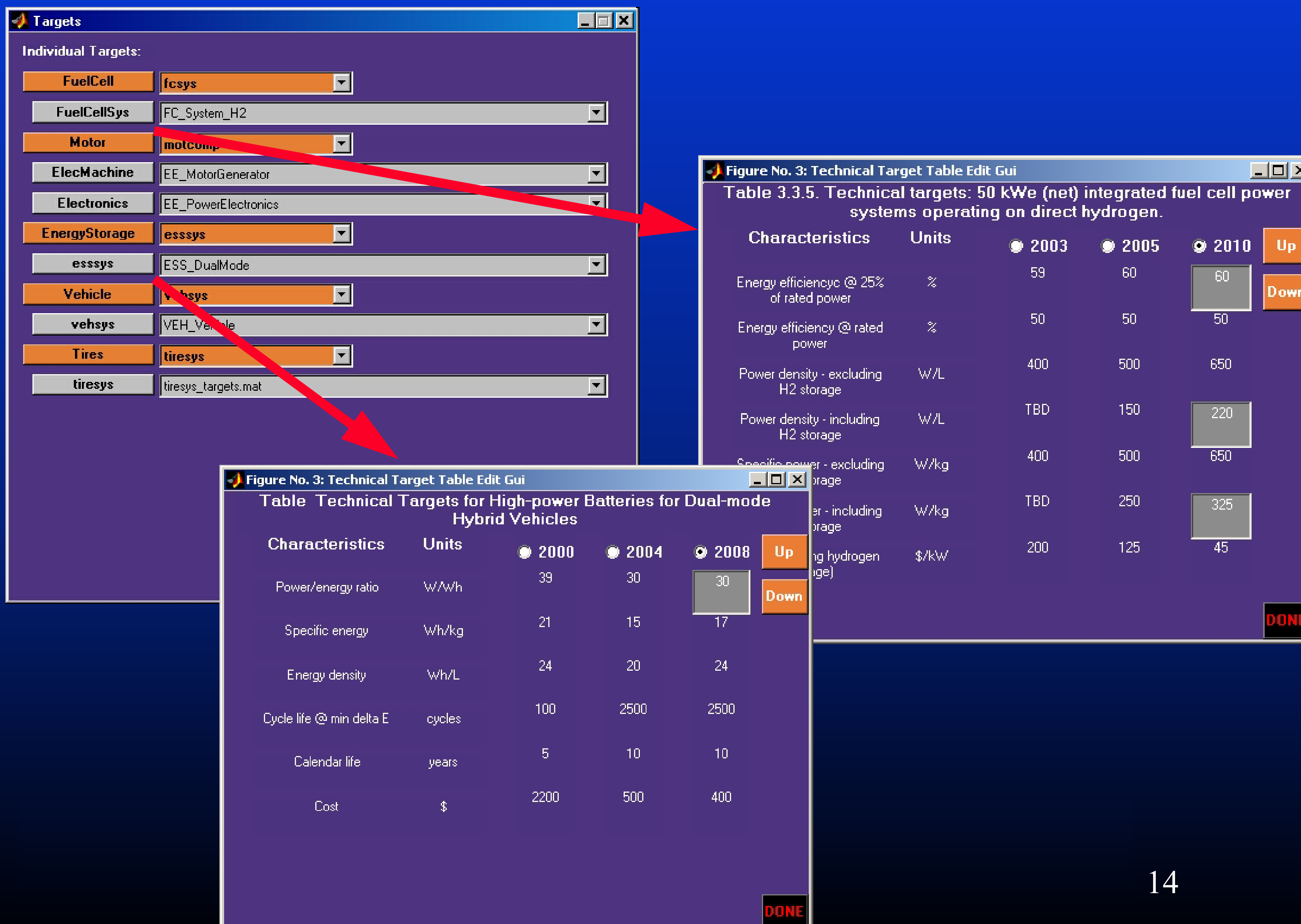
Accomplishments
Technical Targets Tool Developed



Quantifies potential impact of DOE programs.

Accomplishments

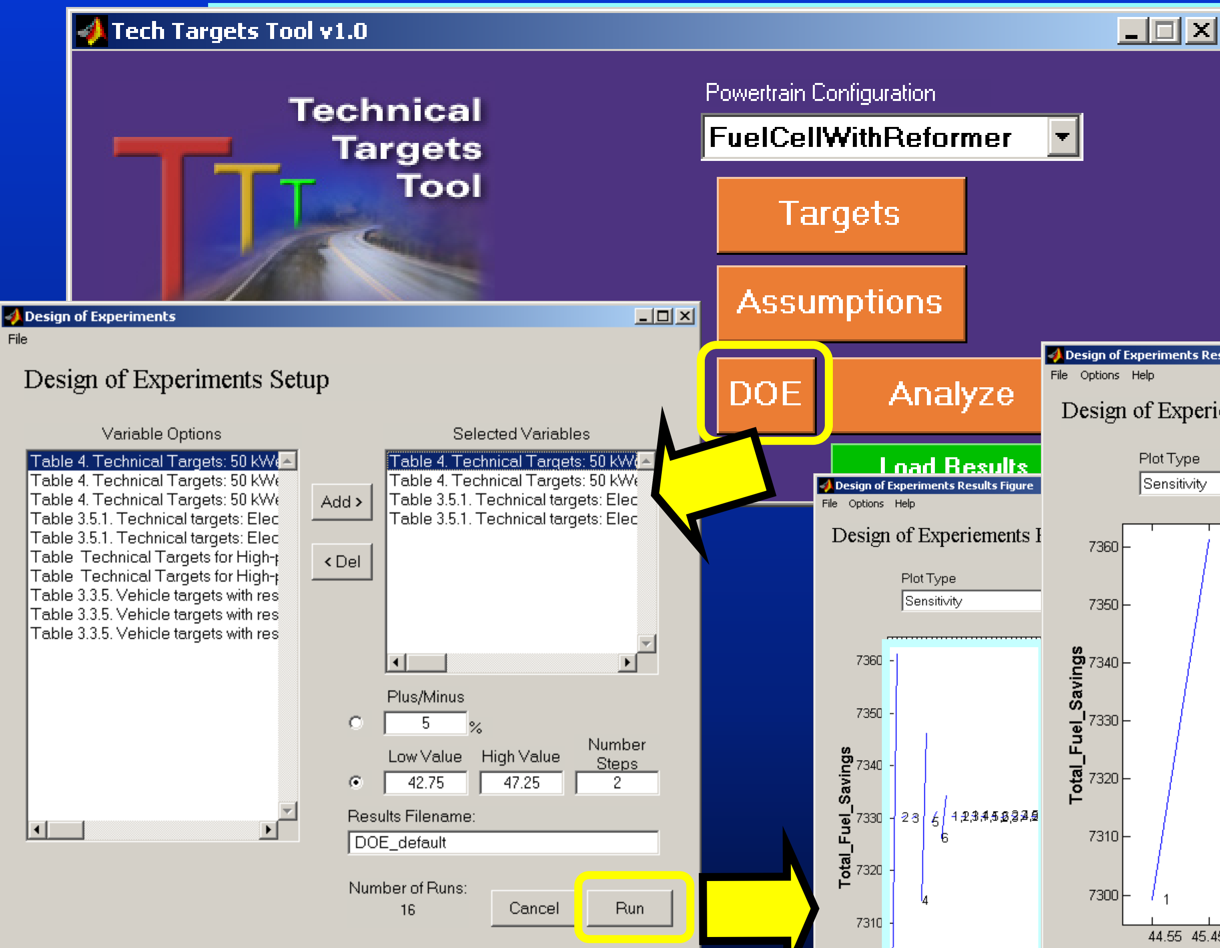
T^3 - A Repository for Component Targets

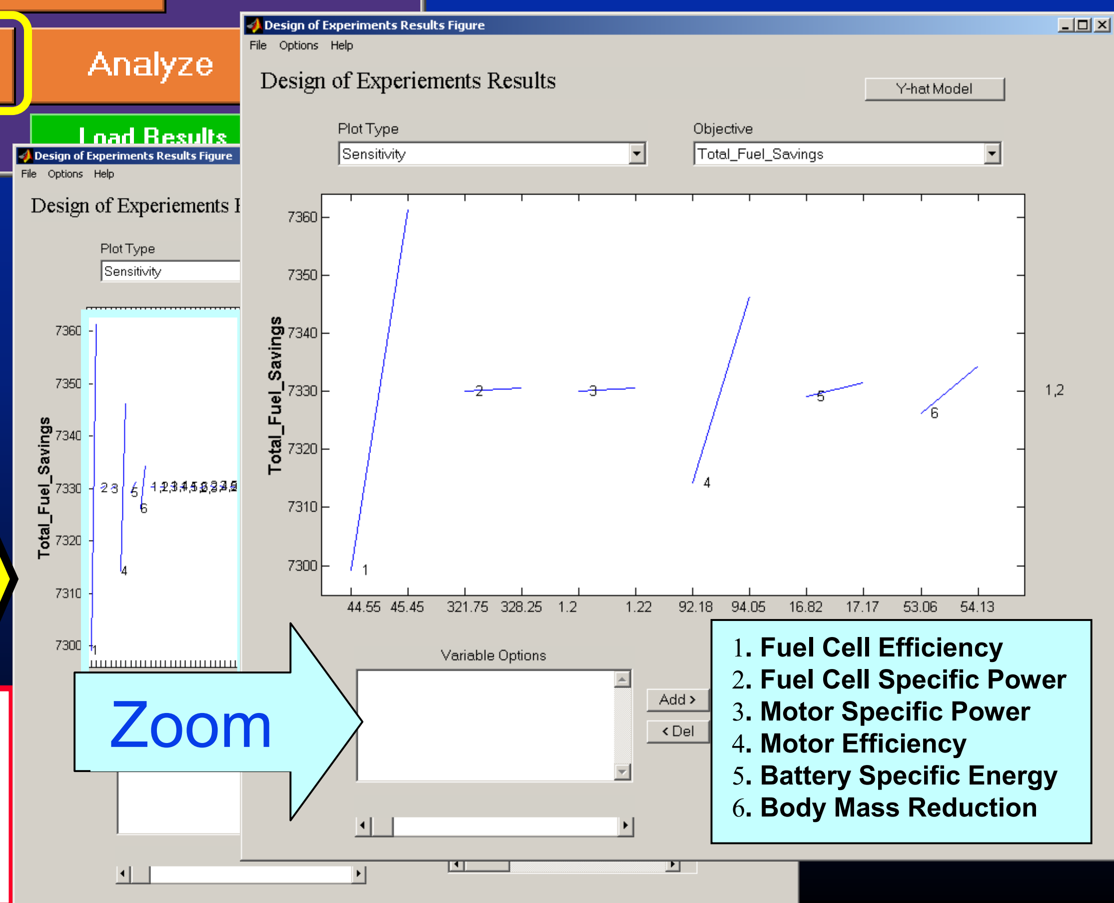


Accomplishments

Fuel Cell Targets Analyzed Using Technical Targets Tool

- Assess impact of technical team component targets at vehicle and fleet level

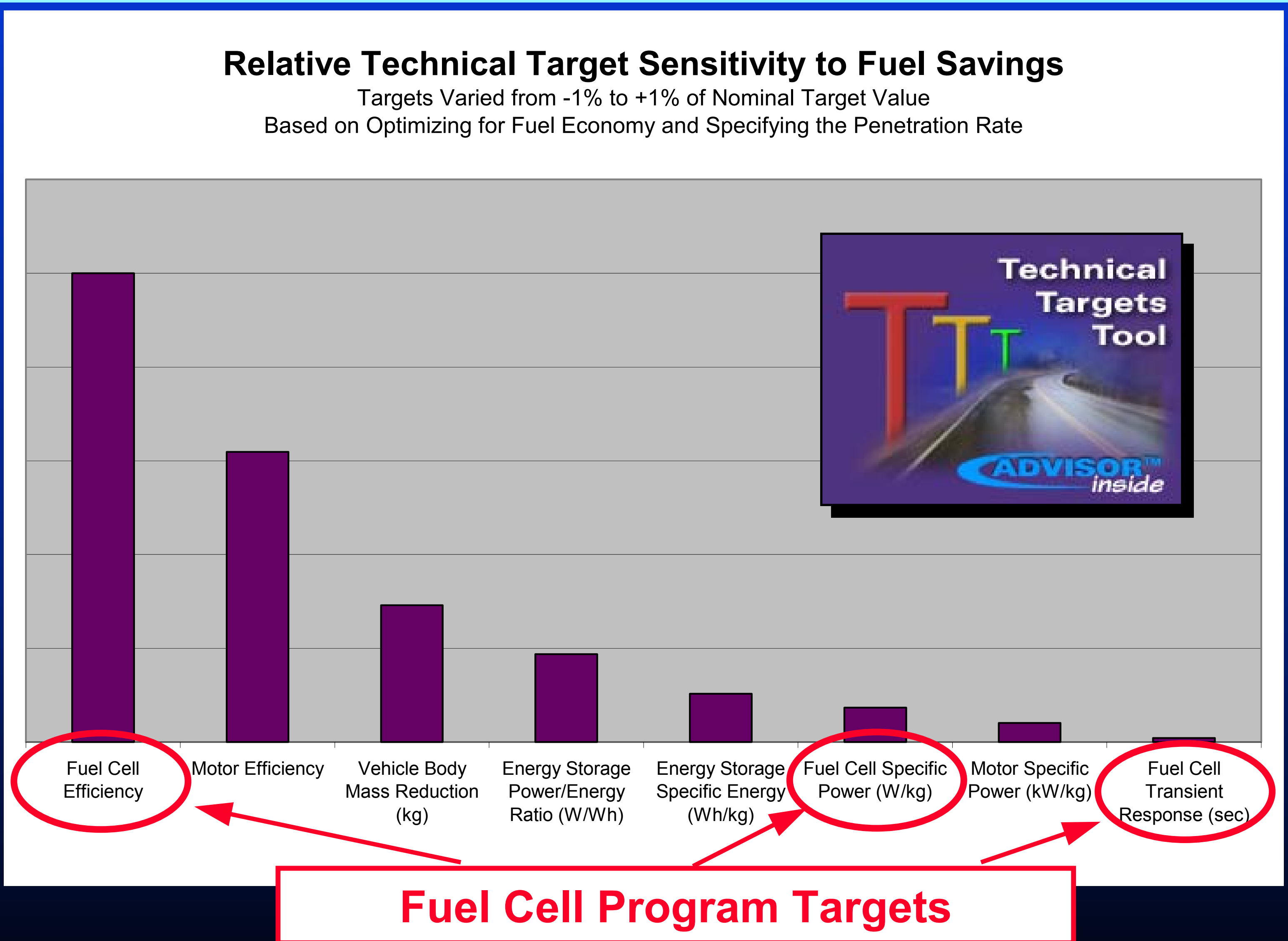




Technical target variation leads to sensitivity in total fuel savings

Accomplishments

T^3 and DOE Highlight Relative Sensitivity of Fuel Economy



High Visibility of NREL's Vehicle Systems Analysis Activity Through Publications

2003-01-2253

Predicting the Fuel Economy Impact of "Cold-Start" for Reformed Gasoline Fuel Cell Vehicles

Keith B. Wipke, Anthony Markel, Kristina Haraldsson
National Renewable Energy Laboratory

Patrick Davis
U.S. Department of Energy

First International Conference on Fuel Cell Science, Engineering and Technology
April 21-23, 2003, Rochester, New York, USA

INNOVATIVE THERMAL MANAGEMENT OF FUEL CELL POWER ELECTRONICS

Kenneth Kelly[1], Andreas Vlahinos[2], Pablo Rodriguez[3] and Desikan Bharathan[4]

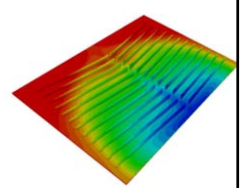


Figure 1 Cooling plate with variable orientation and heigh Fins

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EFFECT OF MATERIAL AND MANUFACTURING VARIATIONS ON MEMBRANE ELECTRODE ASSEMBLY PRESSURE DISTRIBUTION

Andreas Vlahinos[1], Kenneth Kelly[2], Jim D'Aleo[3], Jim Stathopoulos[4]

AN ENGINEERING SYSTEM FOR AUTOMATED DESIGN AND OPTIMIZATION OF FUEL CELL POWERED VEHICLES

Gordon Willis[1], Rick Weller[2] and Keith Wipke[3]
[1] Vulcanworks LLC, Ann Arbor, MI 48113, USA; email: willis@vulcanworks.cc
[2] Vulcanworks LLC, Ann Arbor, MI 48113, USA; email: weller@vulcanworks.cc
[3] National Renewable Energy Laboratory Denver, CO, USA; email: keith_wipke@nrel.gov

AN ANALYSIS OF WATER MANAGEMENT FOR A PEM FUEL CELL SYSTEM IN AUTOMOTIVE DRIVE CYCLES

Kristina Haraldsson – kristina_haraldsson@nrel.gov,
Tony Markel – tony_markel@nrel.gov,
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National Renewable Energy Laboratory, 1617 Cole Boulevard, MS 1633, Golden Colorado 80401-3393

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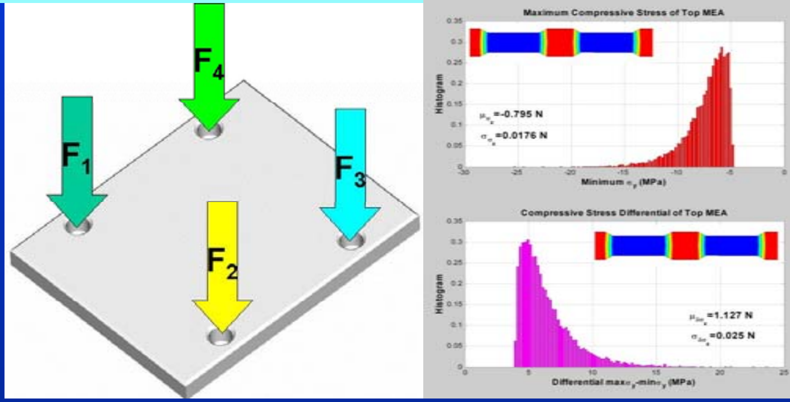
Addressing Reviewer Comments

- System cost estimates should be included in analyses
  - System costs estimated within Technical Targets Tool and recent Energy Storage System Requirements study
- Computer models should be used to evaluate fuel cell program technical targets
  - Technical Targets Tool developed and applied
- Need to accommodate fuel cell and subsystem design trade-offs
  - 2 parametric detailed fuel cell system models integrated with ADVISOR vehicle simulation tool
- Review of assumptions by industry
  - working with fuel cell, hydrogen, energy storage, and vehicle systems technical teams
  - collection of peer reviewed papers published

Recent Collaborative Projects with Industry

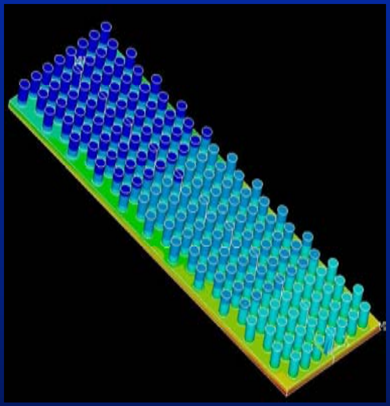
<u>Plug Power:</u>

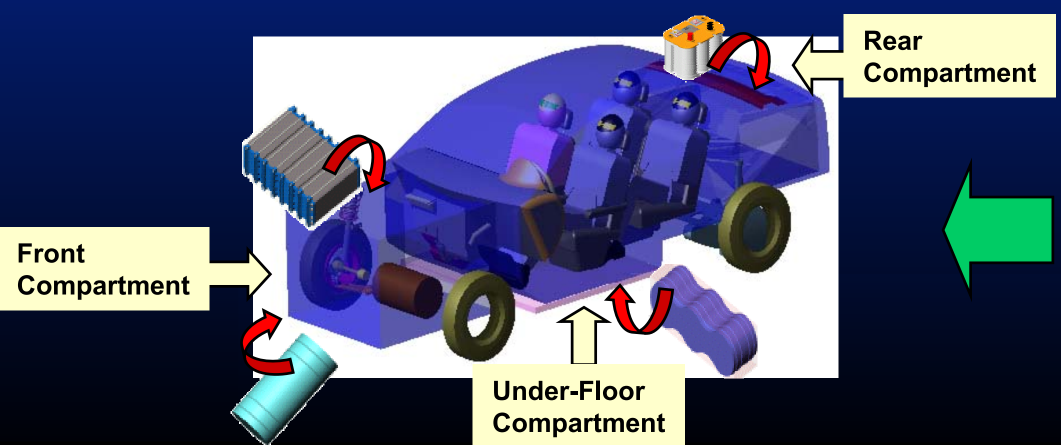
- ATR thermal analysis
- Analysis of MEA pressure profiles
- End plate topology optimization
- Robust high temp. stack design



<u>Ballard Power Systems:</u>

- Thermal management of fuel cell power electronics





<u>VulcanWorks/Nuvera:</u>

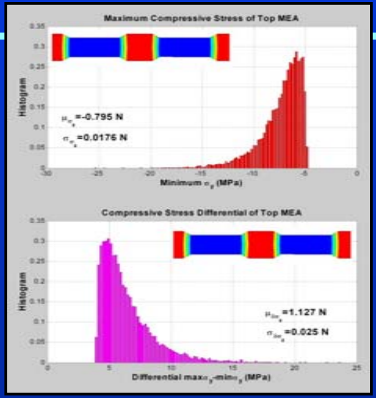
- Design and optimization of fuel cell vehicle packaging solutions

Plans and Future Milestones

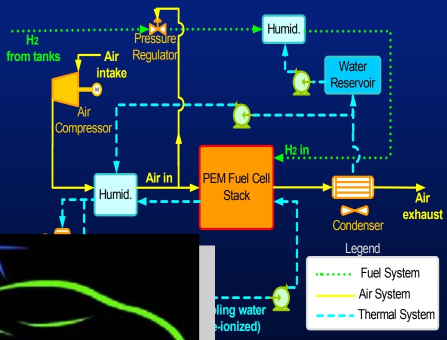
- Fuel cell hybrid vehicle system optimization – working with fuel cell, energy storage, vehicle systems teams on energy storage targets for fuel cell vehicles **(9/03)**
- Technical Targets Tool study on sensitivity of fuel cell technical targets applied to multiple vehicle platforms **(9/03)**
- Complete water and thermal management analysis for fuel cell vehicles under real driving conditions **(11/03)**
- Validation of fuel cell models with industry partners **(2/04)**
- Robust design process transferred to industry to address fuel cell stack cost and durability technical barriers **(9/04)**

Summary

- Vehicle systems tools coupled with optimization and robust design methods are being applied to address cost and durability technical barriers



- Technical Targets Tool introduced and applied to understand sensitivity of fuel consumption to the fuel cell program technical targets



- Enhanced fuel cell system models incorporated into vehicle model to analyze thermal and water management technical barriers